SPECIAL REPORT 91-003

TECHNICAL ADVANCEMENTS IN SIMULATOR-BASED WEAPONS TEAM TRAINING

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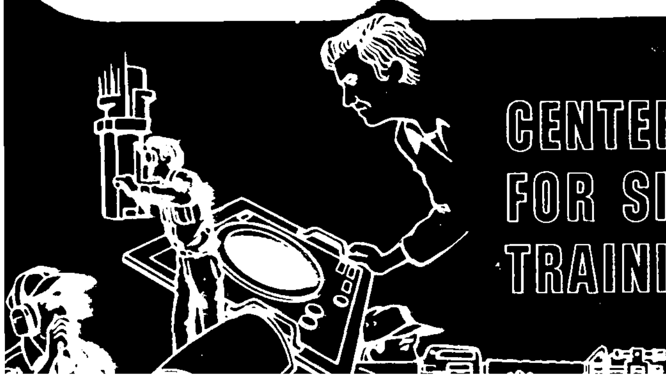

CENTER OF EXCELLENCE FOR SIMULATION AND TRAINING TECHNOLOGY

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TECHNICAL ADVANCEMENTS IN SIMULATOR-BASED WEAPONS TEAM TRAINING

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The research and development reported here represents one phase of a broader effort to improve the effectiveness and realism of training a weapon fire team in a simulator environment. Currently simulator-based team trainers use technology which restricts both realism in tactical training situations and ablility for thorough performance measurements. The overall goal of this development effort is to introduce new technology and techniques which can improve current team training system technology. These new developments include interactive aggressor targets and a high speed weapon tracking system. The Naval Training System Center has developed a test-bed (Weapons Team Engagement Trainer, WTET) which allows two trainees to engage aggressor targets which are presented on a large video projection screen.

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The objectives of the research reported here were: (1) to develop method to remove aggressor targets which are hit as a training scenari progresses; (2) to develop a method which allows aggressor targets to engag and disable trainees who do not take appropriate cover; and (3) to design weapon tracking system which continously and accurately provides weapon ai points for up to 9 trainees.

The Test-bed model constructed at NTSC met the stated objectives Aggressor targets were instantly removed from a training scenario as they wer disabled by weapon fire from trainees. An array of infrared emitting diode was placed above the projection screen and a detector harness was developed t detect a modulated infrared beam from this array. This increased tactica realism in training by requiring trainees to seek appropriate cover whe engaged by the aggressor targets. An innovative weapon tracking system whic generates accurate weapon position data at over 300 Hz was designed an constructed. This device is capable of continuously tracking weapon ai points for up to 9 trainees.

Increased realism and effectiveness in simulator-based weapons tea training can be realized through implementation of these new techniques an technology. Continuously tracking weapon aimpoints for all members of a fi team expands performance measurement capabilities. Training effectiveness an realism are also increased by instantly removing disabled aggressors from th training scenario and requiring trainees to take appropriate cover when a aggressor returns fire. This results in an increase in communication an awareness between members of the team. In contrast, previous training system did not require trainees to seek appropriate cover. Also, aggressor target were not removed from the progressing training scenario when they wer successfully engaged and disabled.

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The authors wish to thank Mr. Joe Porthouse and the model makers of the Laboratory Services Division who performed mechanical design and fabrication for the Weapon Team Engagement Trainer test-bed.

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EXECUTIVE SUMMARY

PROBLEM

The research and development here represents one phase of a broader effort to improve the effectiveness and realism of training a weapon fire team in a simulator environment. Currently simulator-based team trainers use technology which restricts both realism in tactical training situations and ability for thorough performance measurements. The overall goal of this development effort is to introduce new technology and techniques which can improve current team training system technology. These new developments include interactive aggressor targets and a high speed weapon tracking system. The Naval Training System Center has developed a test-bed (Weapons Team Engagement Trainer, WTET) which allows two trainees to engage aggressor targets which are presented on a large video projection screen. The new technology and techniques described were demonstrated using this test-bed.

OBJECTIVES

The objectives of the research reported here were: (1) to develop a method to remove aggressor targets which are hit as a training scenario progresses; (2) to develop a method which allows aggressor targets to engage and disable trainees who do not take appropriate cover; and (3) to design a weapon tracking system which continuously and accurately provides weapon aimpoint coordinates for up to 9 trainees.

FINDINGS

The Test-bed model constructed at NTSC met the stated objectives. Aggressor targets were instantly removed from a training scenario as they were disabled by weapon fire from trainees. An array of infrared emitting diodes was placed above the projection screen and a detector harness was developed to detect a modulated infrared beam from this array. This increased tactical realism in training by requiring trainees to seek appropriate cover when engaged by the aggressor targets. An innovative weapon tracking system which generated accurate weapon position data at over 300 Hz was designed and constructed. This device is capable of continuously tracking weapon aiming points for up to 9 trainees.

CONCLUSIONS

Increased realism and effectiveness in simulator-based weapons team training can be realized through implementation of these new techniques and technology. Continuously tracking

weapon aiming points for all members of a fire team expands performance measurement and playback capabilities. Training effectiveness and realism are also increased by instantly removing disabled aggressors from the training scenario and requiring trainees to take appropriate cover when an aggressor returns fire. This results in an increase in communication and awareness between members of the team. In contrast, previous training systems did not require trainees to seek appropriate cover. Also, aggressor targets were not removed from the progressing training scenario when they were successfully engaged and disabled by trainees.

RECOMMENDATIONS

The authors recommend development of an advanced prototype which would further increase realism in the training environment. An engineering model could be developed for potential user tests to determine both training and cost effectiveness. This engineering prototype could enhance both realism and performance measurements by:

(1) eliminating cords interfacing weapons to computers.
(2) allowing up to 9 trainees to rehearse tactical situations.
(3) using multiple screens to increase trainee mobility;
(4) tracking each trainees movements within the training area to both control shoot-back and enhance feedback.
(5) presenting results in a split screen display to show both trainee movement, aggressor actions, and others results.
(6) analyzing the performance results using an expert system.
(7) using an expert system to generate aggressor actions based on team performance.

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INTRODUCTION

The requirement to maintain a high state of readiness during austere budget times and to simulate close combat training effectively has placed new requirements on the training device community. Increased use of small echelon military operations to perform anti-terrorist, anti-drug and law enforcement functions have placed some unique and new emphasis on simulation and training.

The Naval Training Systems Center has developed a Weapons Team Engagement Trainer (WTET) test-bed that will allow two trainees to practice and rehearse close combat training exercises such as low intensity conflict, light infantry, SWAT and security operations with an unsurpassed level of realism and feedback. Typical events might include security operations, hostage rescue, shoot-no-shoot, ambush training situations and routine law enforcement operations in a common team scenario environment.

A typical trainee can expend over 5,000 rounds of ammunition during one week of live fire training. It is expected that the average trainee will use $905.00 worth of ammunition each week. If fifty trainees use the training device each week a potential cost savings of $45,250.00 would be realized each week. These savings do not include the cost of facilities, ranges, fuel, and transportation to and from the live fire ranges. As can be seen the potential cost savings in ammunition alone are very beneficial.

Safety is also a concern during live fire training exercises. Since the WTET uses no live ammunition the dangers of an inadvertent weapon discharge or lead poisoning is eliminated entirely.

PROBLEM

The research and development here represents one phase of a broader effort to improve the effectiveness and realism of training a team in a simulator environment. Currently simulator-based team trainers use technology which restricts both realism in tactical training situations and ability for thorough performance measurements. The overall goal of this development effort is to introduce new technology and techniques which can improve current team training system technology. These new developments include a high speed weapon tracking system and interactive aggressor targets. The Naval Training System Center has developed a test-bed, Weapons Team Engagement Trainer (WTET) which allows two trainees to engage aggressor targets which are presented on a large video projection screen. The new technol-

ogy and techniques described are demonstrated using this test-bed.

OBJECTIVE

This report highlights new technology that was developed under the WTET research effort. This new technology will allow for effective and realistic training of small echelon military operations previously unobtainable through simulation. The authors identified what they determined to be three major weaknesses which limit the effectiveness of existing team trainers. These weaknesses are as follows:

1. **Aggressors are not removed from the scenario when hit as they are in the real world.** Trainees can not adjust their strategy based on other team members performance since this information is not readily apparent (i.e., killed targets remain in the scenario).

2. **Trainees are not required to seek sensible cover and concealment.** Team trainers currently available permit the trainees to engage targets while fully exposed to on-screen aggressors since here is no aggressor shoot-back.

3. **The tracking system** for determining the aiming point of the trainees' weapon's is limited to collecting data only at trigger-pull. As a result, continuous weapon position data is not available for replay, analysis, and feedback. There is also a substantial delay between trigger-pull and data collection proportional to the number of trainees in the team trainer.

The testbed model was developed to perform research and development on the three basic weaknesses previously addressed. Funding constraints and the potential size of a nine member team trainer mandated the initial research model to accommodate only two trainees. However, the technology developed from the research effort is readily applicable to a full scale WTET capable of handling up to nine trainees simultaneously.

SYSTEM OVERVIEW

The WTET test-bed accommodates training for two military or law enforcement trainees in a common-threat scenario. The trainees interact with a 100 inch video projection screen set up in a training exercise room. The video projection screen displays both live video targets and graphics overlay from a video projector and a video disk player under computer control. Each trainee has a weapon that is equipped with a collimated source of infrared (IR) energy, an infrared emitting diode (IRED). Figure 1 illustrates the configuration of the WTET test-bed. The IRED is collimated to maximize the IR energy transferred from the weapon to the projection screen while

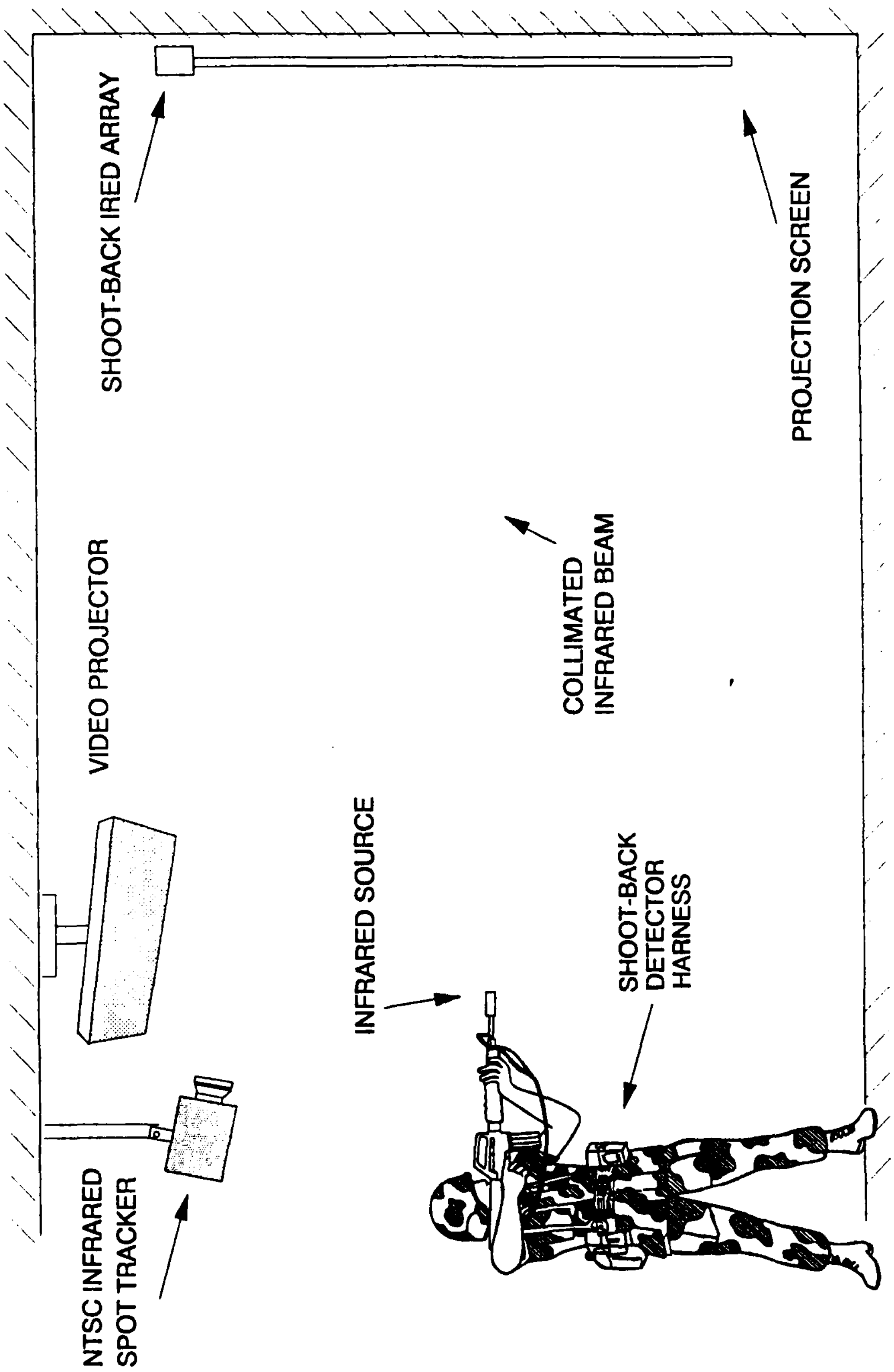

Figure 1. Weapons Team Engagement Trainer Configuration

minimizing the IR beam divergence. The collimated infrared source is aligned with the trainee's weapon and places a small infrared spot on the video projection screen corresponding to the location the trainee is pointing his weapon. Figure 2 shows the collimated infrared source and its location on the M-16 rifle. The infrared sources are sequentially modulated in a time multiplexed mode by the system computer to both identify the active weapon and to improve signal detection.

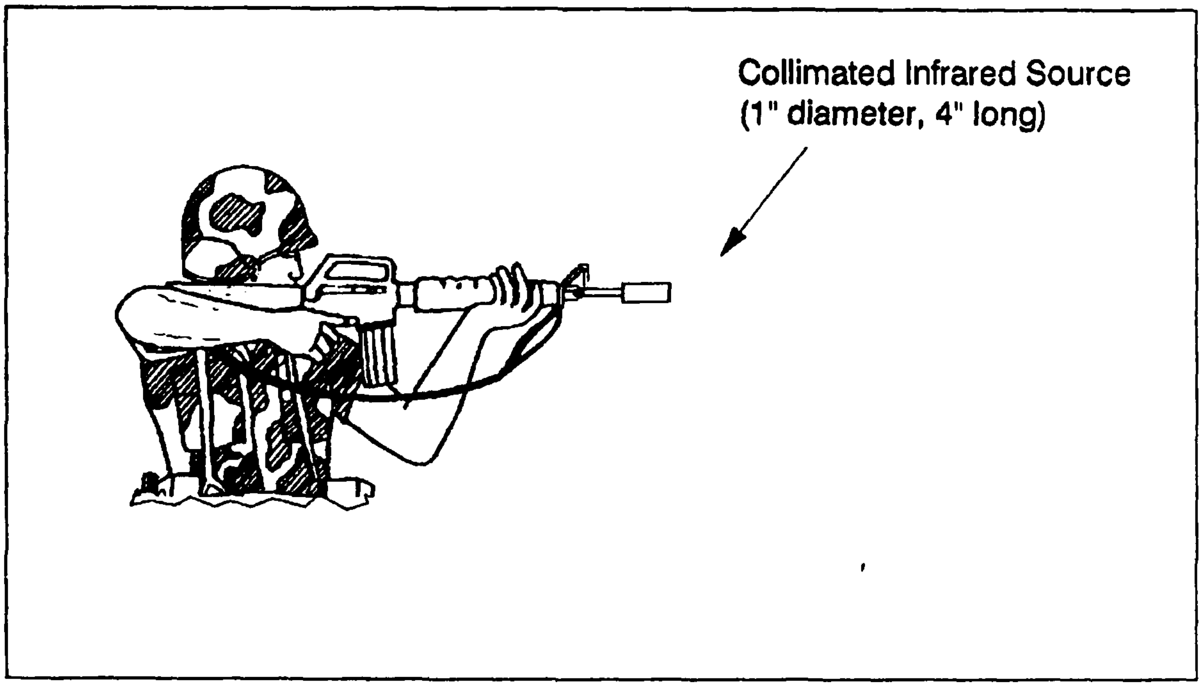

Figure 2. Collimated Infrared Source Mounted on M-16 rifle.

A high-speed, low cost, infrared spot tracker determines the continuous X and Y position coordinates of each weapon. The optical system for the infrared spot tracker (IST) views the entire video projection screen from a distance of approximately 12 feet. The infrared spot imaged onto the projection screen surface is optically transferred or reimaged to a corresponding location on the Position Sensing Detector (PSD) as shown in Figure 3. The PSD and associated electronic circuitry is located within the IST enclosure. The system computer determines the position coordinates of the infrared spot on the PSD and consequently the video projection screen as well.

The high-speed PSD-based infrared spot tracker, designed as part of the research model generates the continuous position coordinate data of each weapon in less than 3 milliseconds; in contrast, a typical CCD-based tracker would require over 16 milliseconds. Due to the high-speed tracking capability of the PSD-based tracker, the WTET allows for accurate tracking and

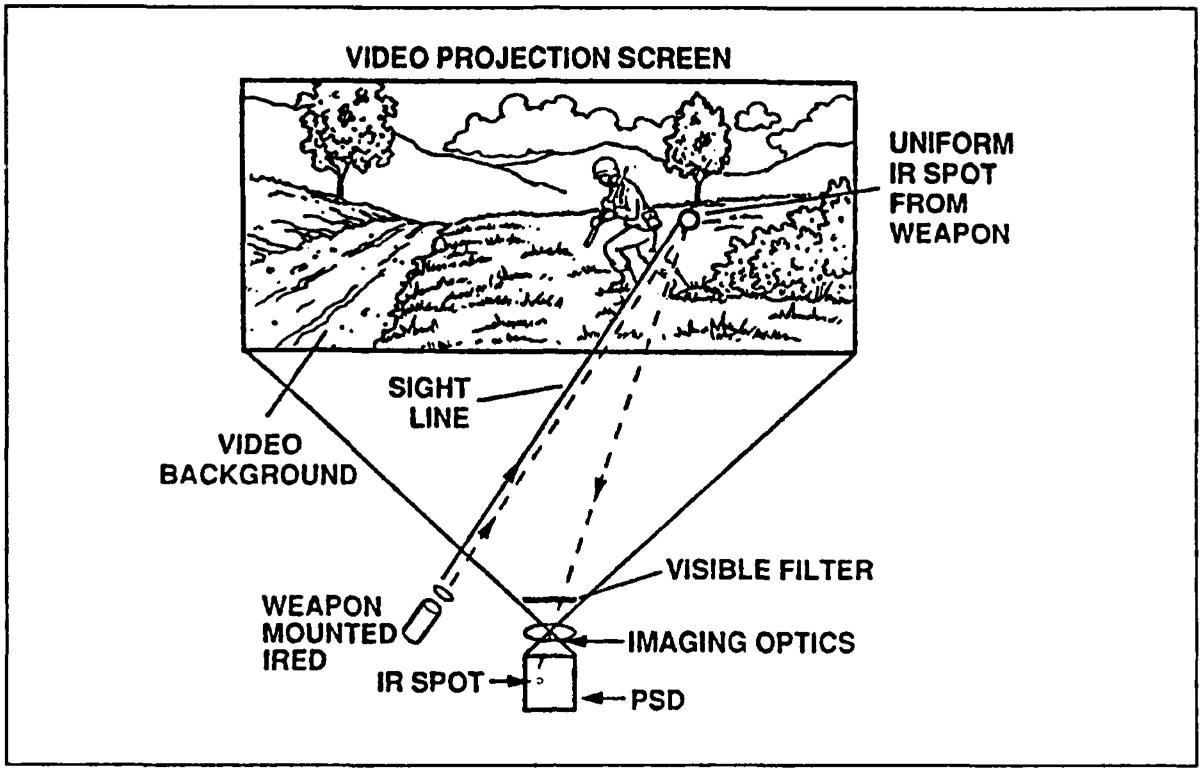

Figure 3. Infrared Spot Tracker Imaging Diagram

trigger-pull synchronization for up to nine trainees.

The system computer synchronizes the time-multiplexed enable signal for each weapon with the 12-bit analog to digital conversion of the IST position data. Once the system computer knows the position coordinates of a weapon, it can compare that data to the stored coordinates of active targets on the projection screen at the time of trigger pull. If the IST position data matches the coordinates of a target on the projection screen, a hit is recorded for that weapon. A high-speed video graphics board utilizing "active windows" enables the targets to disappear when hit without affecting the ongoing scenario. The ability to have targets disappear after they have been hit is very important in a team trainer. Other team members now know that this target has been hit, and they can adjust their strategy accordingly.

A block diagram of the WTET testbed components is illustrated in Figure 4.

The trainees are encouraged to take sensible cover as they would in the real world while engaging targets displayed on the video projection screen. Each trainee wears a Multiple Integrated Laser Engagement System (MILES) torso harness containing

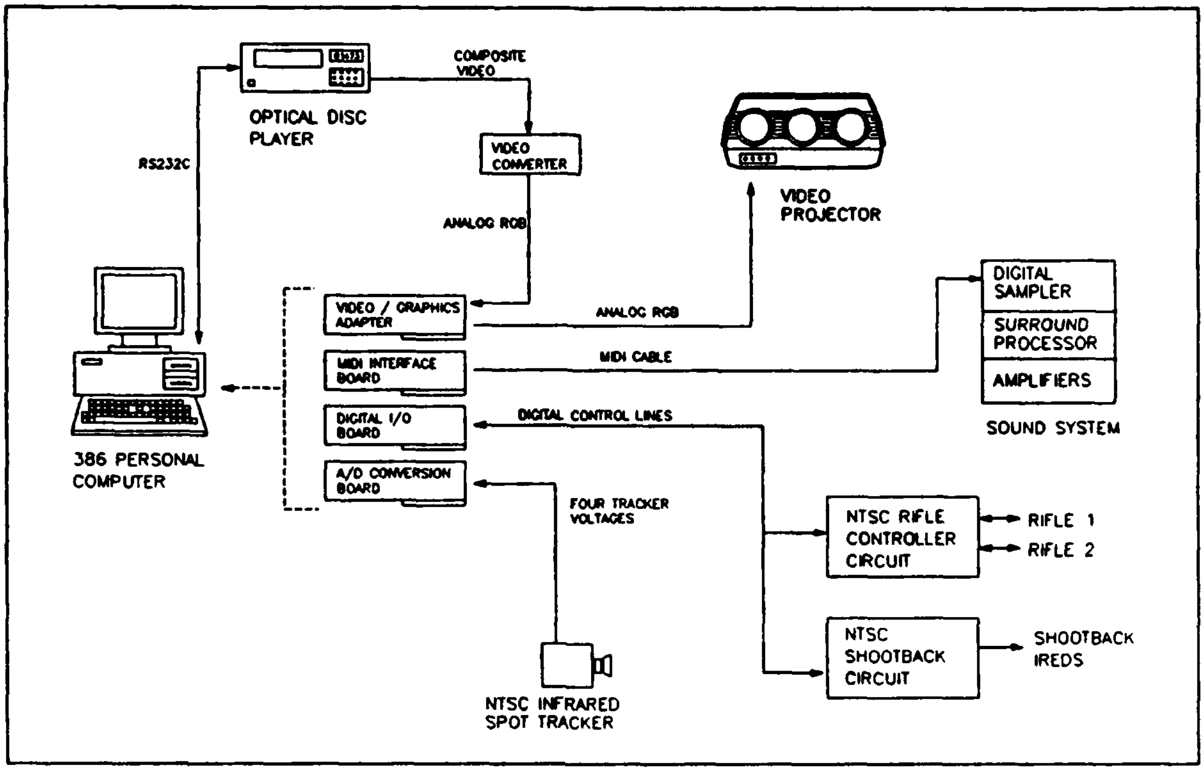

Figure 4. WTET System Block Diagram

infrared detectors and an alarming device to indicate if he has been hit by an on-screen aggressor. The on-screen aggressor shoot-back is simulated by using an array of infrared emitting diodes (IREDs) located above the video projection screen. Each IRED is pointed in a particular sector within the training exercise room so that all exposed areas are within the field of fire of the on-screen aggressors. The individual IREDs are turned on and off by the system computer corresponding to where the on-screen aggressor is pointing his weapon. If a trainee does not take cover while in the field of fire of the on-screen aggressors he will be illuminated with infrared energy. The infrared detectors positioned on the MILES torso vest will detect the incident IR energy and activate an alarm to indicate that the trainee has been shot by the on-screen aggressor. Once a trainee has been hit he is considered dead and his weapon is disabled.

After a training session is over, the video scenario is played back in slow motion. The system computer shows the continuous pointing location of each weapon by graphically displaying color coded icons representing the continuous IST position data stored by the system computer during the actual training session. Hit and miss shot locations are indicated by changing the color of the icons.

A complete sound system has also been developed to simulate the actual acoustical training environment of each scenario. An Analog/Digital sampler digitizes, stores and plays back the background sounds as well as the synchronized gun shot sounds corresponding to the trainees and the on-screen aggressors. The sampler is under the control of a Musical Instrument Digital Interface (MIDI) port interfaced to the system computer for proper timing and synchronization.

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SYSTEM DESCRIPTION

SCENARIO AND SOFTWARE DEVELOPMENT

Several software programs, written in C under the MS-DOS operating system, control both training scenario development and presentation for the WTET. Computer software control of the optical disc player allows automated scenario development and rapid aggressor selection. Control of the weapon tracking system hardware provides continuous tracking of each weapon's aimpoint and status. Various functions of the video graphics adapter allow interactive control of the on-screen aggressors. Commands transmitted by MIDI (Musical Instrument Digital Interface) provide sound effects as each scenario progresses. Synchronous control of the WTET system hardware based on the scenario content creates the training session.

Scenario Development

Moving video footage from an optical disc player generates the WTET aggressor threat. Scenario development begins with formulation of a script for the aggressor force. The script describes aggressor actions including timing and movement within the camera's field of view. Creating interactive aggressors (i.e., aggressors disappear when hit) imposes some restrictions on the video recording process. Scenario constraints include maintaining a stationary camera, restricting overlap of aggressor targets, and sustaining consistent lighting. However, these constraints enable instant feedback through disappearing targets and increase flexibility in aggressor selection.

Creating aggressor targets which disappear when hit requires consistency in background and lighting of the video image. These factors are crucial during portions of a scenario where aggressor targets are visible and engageable. Each scenario's moving video can be sectioned into segments in which an aggressor appears into view, engages the trainee, and then takes appropriate cover. Dividing a scenario's moving video footage into sections maximizes optical disc storage by eliminating nonessential video. During each section, camera stability and lighting consistency allow the video graphics adapter to add or remove aggressor targets as a training session progresses.

Depending on the type of scenario, movement of the camera may be necessary to recreate the threat situation. For example, a security force clearing a building would maneuver through the building. Therefore, maneuvering the camera is necessary to produce this type of scenario. To allow for this type of camera movement the scenario script specifies locations where aggressor

engagements occur. Before aggressors are introduced into the scenario, the camera position is fixed at a designated location which maintains a consistent background. From this location, multiple aggressor actions are recorded. The camera is then maneuvered to the next designated area and the process is repeated. Recording multiple aggressor actions at each location enables the training session to branch based upon the trainee performance. These video segments of aggressor engagement and camera movement are edited and transferred to optical disc.

Scenario Processing

After transferring a scenario's video segments to optical disc, a program generates a detailed description or map of each segment. This program automates this mapping process by using a user-friendly menu system, graphical overlays under mouse control, and optical disc control functions. The mapping process generates a data file specifying each video segment. First, the optical disc is scanned to locate the start frame for a video segment. Once located, the number of aggressor targets is identified and entered. For each target, a rectangle is drawn around the area which covers the complete exposure or path of the aggressor target during the video segment. This rectangle defines the live video window used to interactively control each aggressor. By single stepping the optical disc both hit areas and shootback directions are identified for each frame of the video segment. Specifying a unique filename for each segment's mapping data creates a data base which describes every video segment applicable to a specific training scenario.

Interactive Targets

The purpose of this detailed mapping process is to allow a video graphics adapter to interactively present the aggressor force during a training scenario. The optical disc player composite video output is converted to an analog RGB signal for input to the video graphics adapter. The video graphics adapter is configured for a 756 x 972 pixel display buffer which is capable of storing two high resolution video frames, each containing 756 x 486 pixels. The video graphics adapter performs real-time capture of the video image at 16 bits per pixel. This 16 bit per pixel format allows the display of both live video and high resolution graphics. Addition and removal of aggressor targets is accomplished by opening and closing live video windows within the captured video image. Closing a live video window while using a double buffer drawing technique allows instantaneous removal of the aggressor target.

Tracking System Software

Software control of the tracking system hardware allows each weapon to be continuously monitored during a training

scenario. The hardware is comprised of a newly developed infrared spot tracker based on a position sensing detector (PSD), an analog to digital (A/D) conversion board, a high powered infrared emitting diode (IRED) mounted on each weapon, and control electronics. Each weapon's aimpoint, trigger switch position, selector switch position, and magazine reload indicator are sampled at approximately 60 Hz.

A periodic interrupt procedure controls the weapon tracking process. The A/D board is configured to acquire the IST's four analog outputs with direct memory (DMA) data transfer, which requires minimal CPU overhead. A programmable interval timer provides timing signals which sequence the process. The programmable interval timer is configured to generate both a 3 millisecond periodic interrupt (rate generator) and a 2 millisecond one shot delay. Activated every 3 milliseconds, an interrupt service procedure controls the weapon tracking process.

The timing sequence for a two weapon system is shown in Figure 5. At the start of the first interrupt cycle weapon one's IRED is activated and the programmable oneshot is retriggered. After 2 milliseconds the infrared spot tracker's

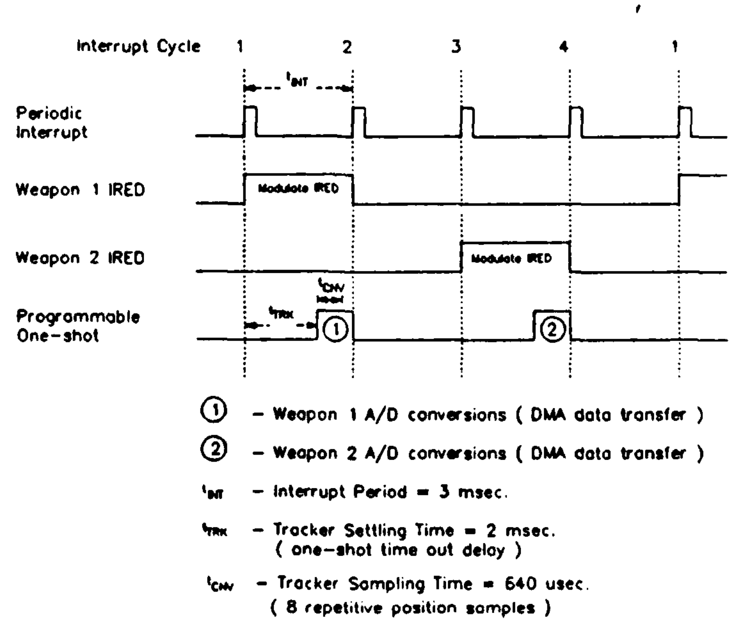

Figure 5. Timing Sequence for Tracking Weapon Aim Points

four analog outputs have settled and reflect the horizontal and vertical position of weapon one's aimpoint. Simultaneously, the programmable oneshot output gates the A/D board to acquire the tracker's four outputs. Each output is converted at 50 kHz to 12-bit digital values. During approximately 640 microseconds the four outputs are sampled eight times and the 12-bit results are DMA transferred into a data buffer. Upon entry of the second interrupt cycle, weapon one's IRED is turned off and the A/D data buffer is monitored. Comparing data buffer elements to a voltage threshold determines the presence of the weapon one's infrared spot. If detected, the tracker's raw data is averaged. Calculations are then used to determine weapon one's non-scaled horizontal and vertical positions. In addition, weapon one's switch positions are updated. Similarly, weapon two's IRED is modulated during interrupt cycle three and positional data is generated during cycle four.

Repetition of this interrupt sequence provides continuous update of each weapon's aimpoint and switch status. Two techniques enable this tracking process to require minimal CPU overhead. First, multiple conversions of the tracker's four analog outputs are performed with DMA data transfer. Second, a periodic interrupt procedure, essentially a background task, performs both tracking system controls and basic position data calculations.

Presently, a simple weapon zeroing procedure is used to find coefficients and offsets for two first order equations. These equations are then used to convert the raw tracking system data to x and y screen coordinates. This method, however, does not maximize the accuracy and stability of the tracking system hardware. Several future improvements will increase the accuracy of the tracking system. First, the weapon alignment algorithm will account for the tracker's viewing angle, the tracker's lens distortion, and the video projector's linearity. Second, optimizing the tracker's imaging optics will increase accuracy. Furthermore, increasing the A/D conversion rate to acquire more samples and improving data conditioning algorithms will improve tracking system performance.

Currently, the WTET is configured as a two weapon system. However, the weapon tracking process is expandable. Additional weapons can be added while achieving sufficient sampling rates, up to 9 weapons at greater than 30 Hz. Also, a larger field of view can be covered through the use of multiple infrared spot trackers.

Scenario Presentation

The WTET system computer controls the presentation of each scenario's moving video footage through a RS-232 communication link to the optical disc player. Synchronizing the moving video

footage to the simulation software provides an event timing mechanism. Each moving video segment is synchronized by initiating the optical disc playback operation and monitoring a vertical sync counter on the video/graphics board. During optical disc playback the current frame number is instantly accessible by reading this counter. This provides an accurate and efficient method for synchronizing the simulation software. In comparison, polling the optical disc player through the RS-232 port requires too much time and CPU overhead.

During a training scenario various segments of moving video footage are presented to the trainees. Target mapping and hit areas are read from a data file located on ramdisk. The simulation is controlled by synchronizing scenario mapping data to the interrupt generated rifle tracking data. An aggressor target is removed from the training scenario when a trainee succesfully fires his weapon within the hit area defined for the current video frame. Weapon sound effects are generated based on both rifle tracking data and aggressor target shoot-back data. Weapon aim points, shot locations, and status are continuously stored for each trainee during the training session. After a training session is completed, this information is provided to the trainees for review.

Scenario Replay

The performance of each trainee is evaluated based on the number of rounds expended, the number of aggressor targets hit, and a visual replay of each weapon's movement with shot locations. Upon completion of a training scenario a replay function performs a slow-motion display of the scenario with graphical overlays. During replay a different colored circle represents each weapon's aim point. Shot locations are indicated by changing the weapon's aim point color and briefly pausing the video playback. An aggressor target hit, a semi-automatic fire miss, or an automatic fire miss is indicated by changing the aim point color to red, blue, or green respectively. The ability to continuously track each weapon's movement enhances both individual and team performance measurements.

AGGRESSOR SHOOT-BACK SYSTEM

The implementation of the aggressor shoot-back system consist of three subsystems: 1) the shoot-back bar, consisting of a horizontal IRED array located just above the video projection screen, 2) the IRED modulator/driver circuitry located in the proximity of the system computer, and 3) the infrared detection circuitry located on the back of the MILES torso vest. The system computer turns the IRED modulator/driver on and off in synchronization with the on-screen aggressors action. If the on-screen aggressor is shooting his weapon towards a particular

sector then the corresponding IRED is enabled and modulated, forcing the trainee to take cover while in that sector.

The shoot-back bar consist of, but is not limited to, nine IREDs with built in lenses placed horizontally across the top of the video projection screen. Figure 6 illustrates the shoot-back IRED array used to simulate aggressor shoot-back. The individual IREDs are mounted on a ball and socket swivel mount

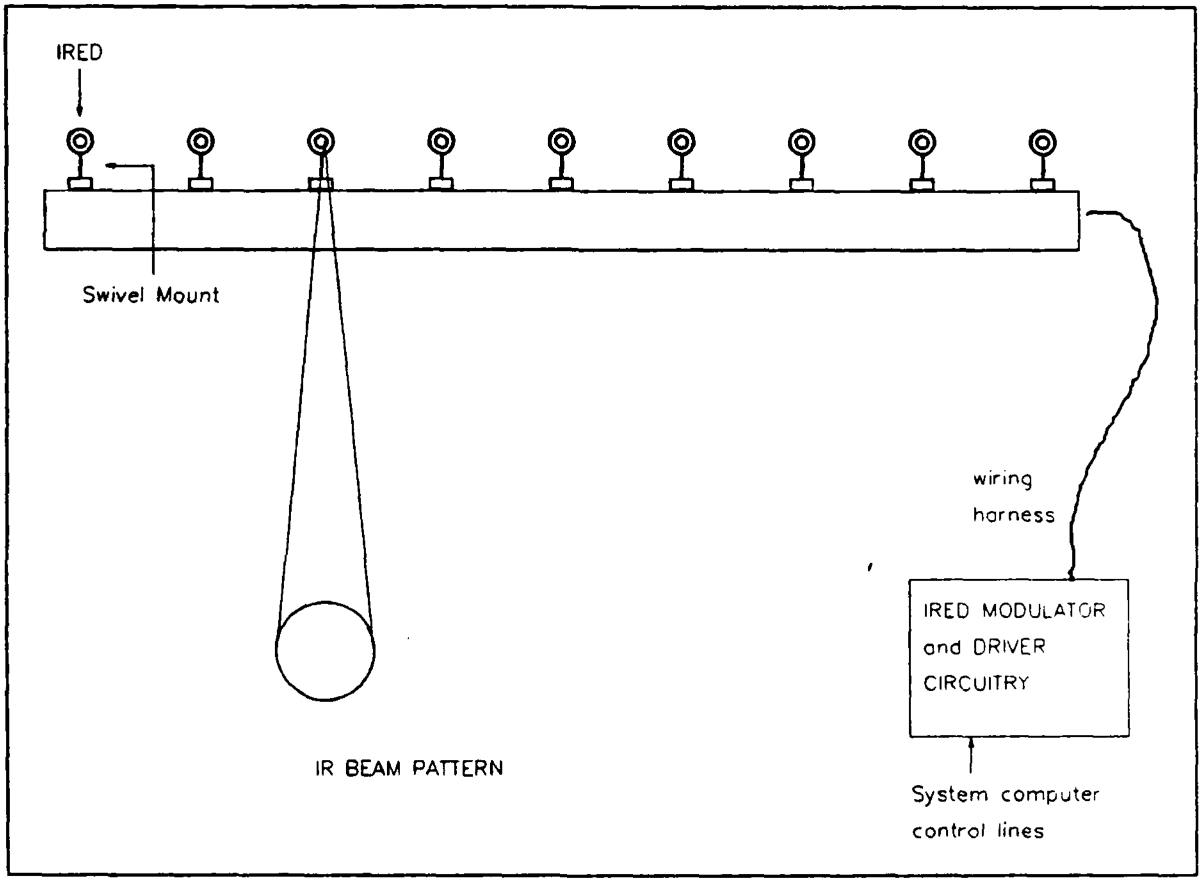

Figure 6. Shoot-back IRED Array Mounted Horizontally Above Video Projection Screen

for optimum adjustment. The IREDs have a half intensity beam angle of less than six degrees. The small beam angle allows the individual IREDs output energy to be strategically directed throughout the training exercise room.

The IREDs are modulated by a 1.6 Khz square wave when enabled by the system computer. Modulating the IREDs allows the driver circuit to pulse more current through the IRED for a higher output power as well as increasing the detectivity of the low level IR signal by the detection circuitry.

The modulator circuit consist of a LM555 timer integrated circuit operating in the astable oscillating mode. The TTL output voltage of the LM555 timer supplies the gate voltage for an Enhancement Mode Junction Field-Effect Transistor (EMJFET) which then sources the required current to IRED.

The IR detection circuitry consist of eight infrared detectors connected in parallel and strategically placed on the MILES torso vest. The original MILES electronics is replaced with specific electronics to detect the modulated infrared energy from the IRED array used to simulates shoot-back. A block diagram of the IR detection system is shown in Figure 7.

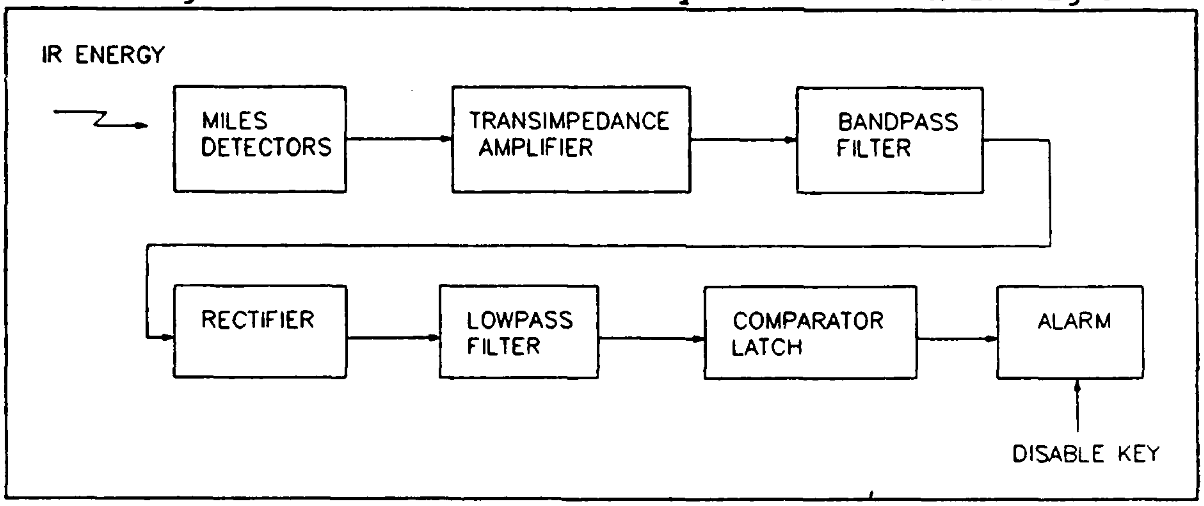

Figure 7. Block Diagram of IR Detection Circuitry

A low noise transimpedance amplifier converts the output current from the photodetectors into a proportional voltage. The infrared signal voltage is amplified and filtered with a fourth order bandpass filter. The output signal from the bandpass filter is rectified and demodulated with a lowpass filter. The lowpass filtered signal is compared to a reference voltage to determine if the trainee was hit by an on-screen aggressor. If a sufficient signal is detected to indicate a hit, then an alarm sounds to indicate to the trainee he has been killed. The alarm is latched with an SCR; therefore the trainee must disable his weapon to utilize a "key" to turn off the hit indicator alarm.

SOUND SYSTEM

Sound effects are generated during a training scenario. The sound system provides sounds of the various weapons being fired by both the trainees and their on-screen adversaries. Also, background sounds are generated to increase realism during a training scenario. The heart of the sound system is a digital

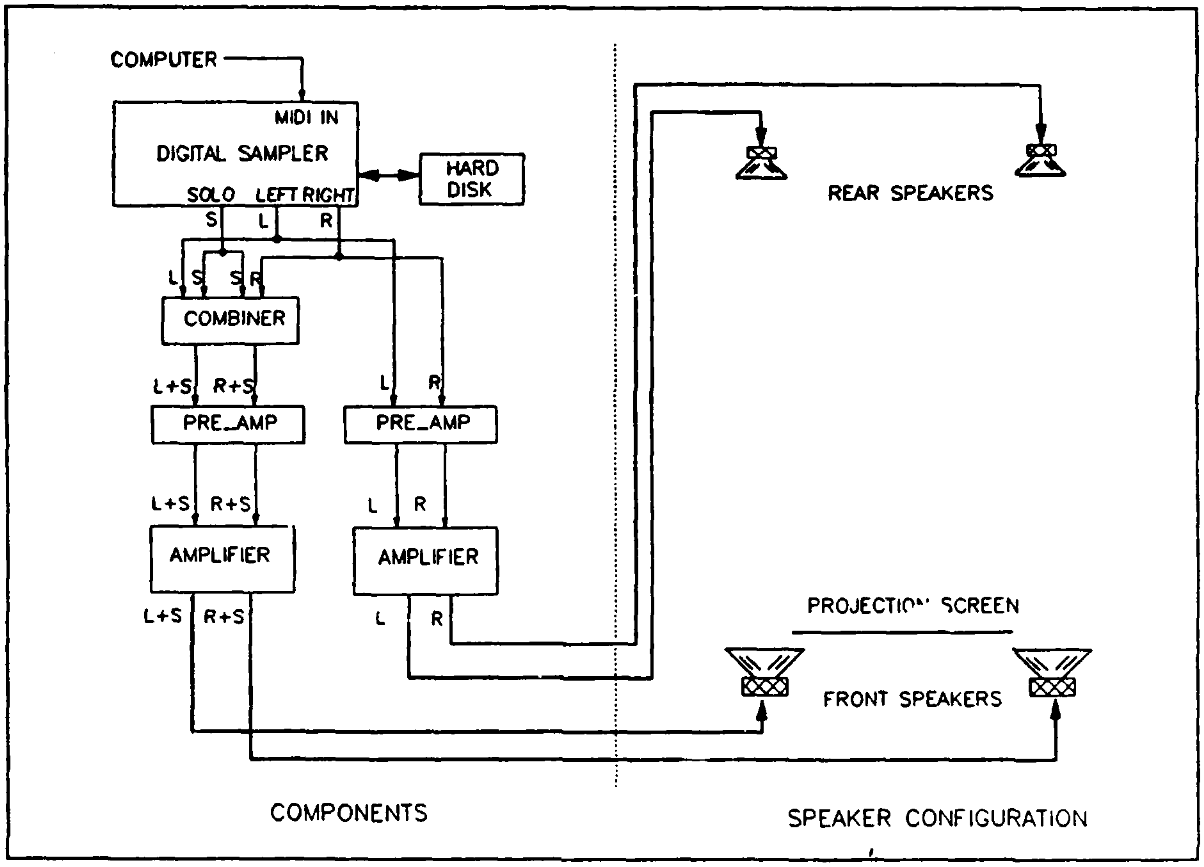

Figure 8. Sound System Components and Speaker Configuration

sampler module. The sampler digitizes, stores and plays back sound effects under the control of a MIDI (Musical Instrument Digital Interface) port. A MIDI controller card is installed in the system computer. During a scenario the computer sends appropriate commands to the sampler via the MIDI interface. The sampler creates the appropriate sounds and sends to amplifiers which drive foreground and background sounds. Mixers are used to control dispersion between the foreground and background. Figure 8 shows the major sound system components and speaker configuration.

Using a sampler module with an external storage device allows a multitude of sound effects to be available for increasing realism in training. The sampler uses both a 3.5 inch 800 Kbyte floppy drive and an 80 Mbyte SCSI hard disk to store digitized sounds. Depending on sample rate, the 80 Mbyte SCSI disk can hold as much as an hour or more of sampled sounds that can be mixed and sequenced by the sampler to generate essentially unlimited amounts of audio feedback. The sounds that are digitized and recreated by the sampler come from a variety of sources. Some are commercially available sound effects pur-

chased on compact disk. Some are recorded in the field using both regular and DAT tape recorders. Still others may be synthesized. The Army's HEL provided several recordings of actual artillery rounds exploding. The sounds have been edited and sometimes normalized before being digitized. Realism and variation in training scenarios is enhanced by adding computer controlled sound effects.

WEAPON TRACKING SYSTEM

An infrared spot tracking system is used in the Weapons Team Engagement Trainer (WTET) to determine the continuous X and Y position coordinates representative of where each trainee is pointing his weapon.

Commercially available infrared spot tracking systems typically consist of a Charge Coupled Device (CCD) video camera interfaced to a digital frame grabber operating at standard video rates. A suitable lens system images the tracking area (i.e., video projection screen) onto the CCD imaging sensor. The frame grabber digitizes each frame of video data collected by the CCD camera. This data is further processed with digital signal processing hardware as well as proprietary software algorithms to find the position coordinates of the imaged IR spot.

The CCD imaging sensor consists of a two-dimensional matrix of discrete photodiode elements. A 10-bit (1024 horizontal elements x 1024 vertical elements) CCD imaging sensor has over one-million individual photodiode elements that convert the incident illumination into a proportional quantity of electrical charges. The electrical charges are sequentially transferred to a readout stage. At the readout stage, each electrical charge is converted into a proportional voltage signal. This voltage is further amplified to give a low impedance output video signal. The charge transfer image is generated in one video frame requiring over 30 milliseconds.

For accurate tracking and trigger-pull synchronization the position coordinates of each weapon should be updated at least every 3 milliseconds with a resolution of 10 bits. The CCD-based tracking system discussed above requires over 30 milliseconds to sequentially sample the weapon position coordinate. This time frame is obviously much too long for the WTET's application of multiple trainees. Another disadvantage of the CCD-based tracking system is the high cost. A complete low-end CCD-based tracking system typically cost over $10,000.

To overcome the disadvantages of the CCD-based tracking system, we developed a low-cost, high-speed, IST utilizing a two-dimensional lateral-effect photodiode, the Position Sensing

Detector (PSD). The PSD is not a discrete charge transfer device such as the CCD, but rather a continuous analog output device. In contrast to other types of position sensing photo devices such as CCD detectors, the PSD offers higher resolution, faster speed, larger dynamic range, and simpler signal processing.

The PSD is a photoelectronic device utilizing the lateral photo-effect [1] to convert an incident light spot into continuous position data. The lateral photo-effect occurs because of the diffusion properties of separated charge carriers along a uniformly or nonuniformly irradiated p-n junction. The current diffusion in a fully reversed-biased p-n junction occurs primarily due to the external collection of generated charge carriers through finite loading impedances [2]. Woltring [3] showed that for the two-dimensional fully reversed-bias PSD with zero loading impedance, there is an analytical linear relationship between the output current and the light spot position along the pertinent axis.

The basic construction of a two-dimensional lateral-effect PSD consist of p and n doped layers of silicon forming a p-n junction. The front side of the PSD is an implanted p-type resistive layer with two lateral contacts placed opposite each other. The back side of the PSD is an implanted n-type resistive layer with two lateral contacts placed orthoganol to the contacts on the front side. The p and n layers are formed by ion implantation to ensure uniform resistivity. As an example, high resistivity silicon can be implanted with boron on the front side and with phosphorus on the back side. The p-n junction is light sensitive; therefore, incident light will generate a photoelectric current which flows through the ion implanted resistive layers. Electrodes are formed at the edges of the PSD by metalization on the ion-implanted resistive layers. Transimpedance amplifiers serve as a finite load impedance to convert the generated charge carriers to a position dependent voltage.

The two-dimensional lateral-effect PSD used in the design of the IST is able to detect an incident light spot position on its rectangular surface with a maximum non-linearity of 0.1 percent. Figure 9 illustrates the two-dimensional PSD structure.

The photoelectric current generated by the incident light flows through the device and can be seen as two input currents and two output currents. The distribution of the output currents to the electrodes determines the light position in the Y dimension; the distribution of the input currents determines the light position in the X dimension. The current to each electrode is inversely proportional to the distance between the incident light position and the actual electrode due to the

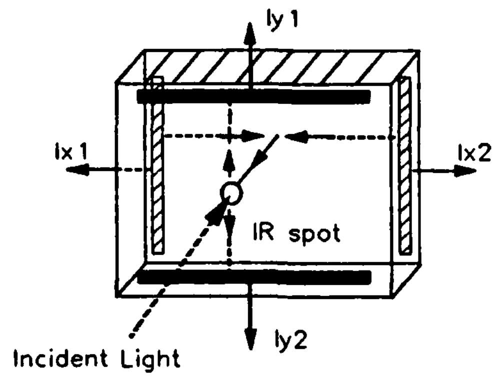

Figure 9. Two-Dimensional PSD Structure

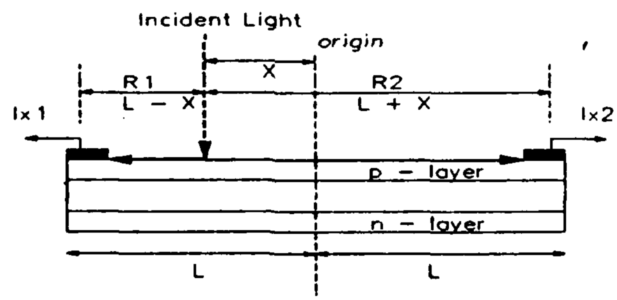

Figure 10. One-dimensional PSD Position Model

uniform resistivity of the ion implanted resistive layers. A one-dimensional PSD position model is shown in Figure 10. This illustrates how simple algebraic equations determine the incident light spot position. This model assumes a zero ohm load impedance and a theoretically uniform implanted resistive layer.

Referring to Figure 10, the distance between electrodes 1 and 2 is 2L, and the uniform resistance is *R*. The distance from

electrode 1 to the position of the incident light spot is L - X, and the resistance is R_1. The distance from electrode 2 to the position of the incident light spot is L + X, and the resistance is R_2. The photocurrents produced at electrodes 1 and 2 are proportional to the incident input energy and inversely proportional to the uniform resistant path from the incident light to the electrodes. The total photocurrent produced by the input energy is I_o. The sum of the output currents I_1 and I_2 is equal to I_o.

From Figure 10, we can derive the following equations,

$$I_1 = I_0 \frac{R_2}{R_1 + R_2} \tag{1}$$

$$I_2 = I_0 \frac{R_1}{R_1 + R_2} \tag{2}$$

The resistance of R_1 and R_2 is proportional to the linear distance that R_1 and R_2 represent since the resistive layer is uniform. In general, the resistance of a given material is given by

$$R = \frac{\rho L}{A} \tag{3}$$

where,

p = resistivity of the material in ohms·meter
L = length of material in meters
A = area of material in meters^2

IF we now define R_1 and R_2 with respect to p, L, and A we obtain the following expressions:

$$R_1 = \frac{\rho (L - x)}{A} \tag{4}$$

$$R_2 = \frac{\rho (L + x)}{A} \tag{5}$$

Substituting equations (4) and (5) into equations (1) and(2),

the output currents I_1 and I_2 can now be written as:

$$I_1 = I_0 \frac{L + x}{2L} \tag{6}$$

$$I_2 = I_0 \frac{L - x}{2L} \tag{7}$$

We can eliminate the dependance of equations (6) and (7) on I_o by dividing the difference of I_1 and I_2 by the sum of I_1 and I_2. We can now solve for the X position (X_{pos}) of the incident input energy relative to the chosen coordinate system shown in Figure 10.

$$X_{pos} = \frac{I_1 - I_2}{I_1 + I_2} \tag{8}$$

Substituting equations (6) and (7) into equation (8) gives

$$X_{pos} = \frac{x}{L} \tag{9}$$

Equation (9) gives the linear position of the incident energy source independent of its intensity. This feature is very important since the intensity of the focused energy source on the PSD surface is rarely constant in a typical application. The two-dimensional PSD position model operates analogous to the one-dimensional PSD position model except that there are now two uniform resistive layers and four electrodes. The top resistive layer is used to divide the output currents into I_{y1} and I_{y2}. The bottom resistive layer is used to divide the input currents into I_{x1} and I_{x2}. The four currents I_{y1}, I_{y2}, I_{x1}, and I_{x2} determine the x and y position coordinates of the incident energy source analogous to the one-dimensional case.
The X position coordinate is given by

$$X_{pos} = \frac{I_{x_1} - I_{x_2}}{I_{x_1} + I_{x_2}} \tag{10}$$

The Y position coordinate is given by

$$Y_{pos} = \frac{I_{y_1} - I_{y_2}}{I_{y_1} + I_{y_2}} \tag{11}$$

Equations (10) and (11) clearly show that we may obtain the X and Y position coordinates of an incident energy spot focused onto the PSD surface by a simple manipulation of the output photocurrents.

Since it is the magnitude of the photocurrents that we wish to manipulate we can represent the four output currents with four output voltages as long as we preserve the magnitude information. We now have the following design equations:

$$X_{pos} = \frac{V_{x_1} - V_{x_2}}{V_{x_1} + V_{x_2}} \tag{12}$$

$$Y_{pos} = \frac{V_{y_1} - V_{y_2}}{V_{y_1} + V_{y_2}} \tag{13}$$

The design of the analog electronic subsystems for the PSD-based tracker is dependent on the amount of reflected IR energy collected and focused onto the PSD surface. This energy is a function of the IR energy source mounted on the weapon, the projection screen reflectivity, the angle of incidence of the collimated energy source to the projection screen, and the collecting optics used to collect and focus the reflected IR energy onto the PSD surface.

The electronic design of the IST consist of six functional blocks as shown in Figure 11. The lens system as previously discussed images the video projection screen onto the PSD surface, thereby imaging the modulated IR spot on the PSD accordingly. The PSD's photo-voltaic effect converts the modulated IR energy focused on its surface into four separate photocurrent outputs. The voltage representation of the magnitude of the photocurrent outputs are used to calculate the spot position on the PSD surface according to equations (12) and (13).

The photocurrent outputs from the PSD electrodes are terminated into low noise transimpedance amplifiers. Figure 12 illustrates a typical dc coupled transimpedance configuration with a bias potential for reverse biasing the p-n PSD junction.

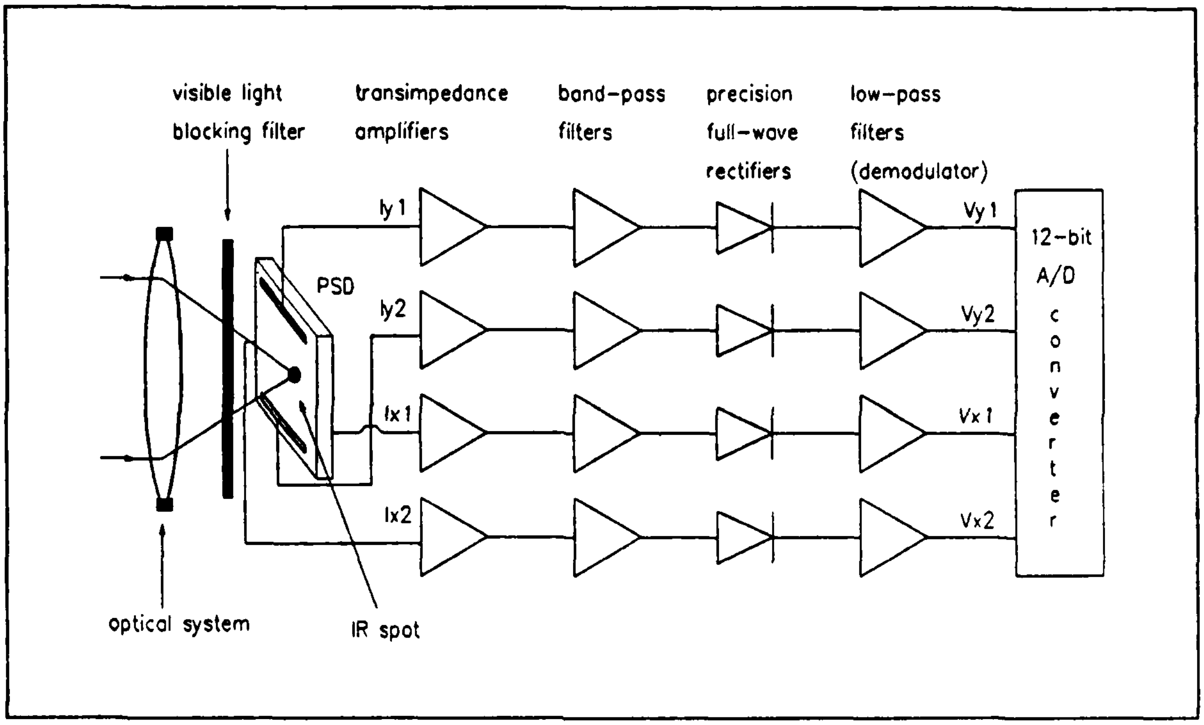

Figure 11. Infrared Spot Tracker Block Diagram

In this configuration, the PSD views a load impedance $Z_L(s)$ defined as

$$Z_L(s) = \frac{R_f}{A(s)\left[R_f C_f s + 1\right]} \qquad \textbf{(14)}$$

where,

$A(s)$	is the amplifier's open-loop transfer function
w	is the modulating frequency of the IRED
R_f	is the feedback resistor
C_f	is the feedback capacitor

To maximize the lateral photo-effect and the linearity of the PSD output currents, the terminating load impedance $Z_L(s)$ should be much less than the position sensing sheet resistance of the PSD [3]. As can be seen from equation (14), this limits the magnitude of the feedback resistor and the modulating frequency of the IRED for optimum performance.

The transimpedance amplifier converts the generated charge carriers from the PSD to a representative voltage.

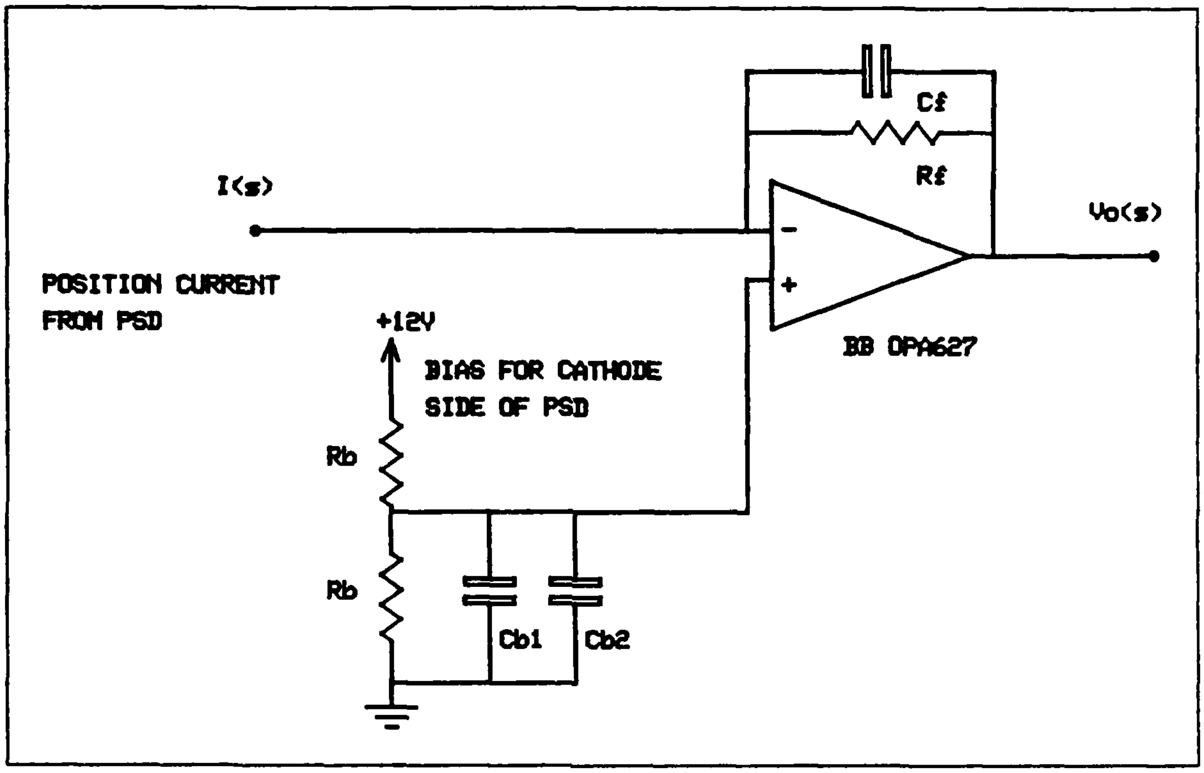

Figure 12. DC Coupled PSD/Transimpedance Amplifier Configuration

The output voltage of the transimpedance amplifier is given by,

$$V_o(s) = I(s)\left[\frac{R_f}{R_f C_f s + 1}\right] + V_n(s) + V_{os}(s) \qquad \textbf{(15)}$$

where,

$V_o(s)$	is the output voltage of the amplifier
$I(s)$	is one of four modulated PSD output currents
$V_n(s)$	is the total output noise voltage including shot noise, thermal noise, and amplifier noise
$V_{os}(s)$	is the total offset voltage due to the dark current and amplifier bias currents

The low-level dc coupled output voltage from the transimpedance amplifier is band-pass filtered with a wide-band fourth order Butterworth filter. The band-pass filter suppresses the unwanted background signal (e.g., room lights), the reverse bias voltage, the offset voltage, and the output noise from the transimpedance amplifier while amplifying the 10 KHz IR signal from the trainee's weapon.

The band-pass filtered signal is further amplified and converted back to a modulated dc voltage level by a precision full-wave rectifier circuit. The dc restoration enables the original dc modulated 10 KHz photocurrent magnitude information to be retained as a dc modulated 20 KHz time varying voltage with a nonzero average.

The full-wave rectified signal is low-pass filtered (demodulated) with a fourth-order Bessel filter to remove the ac Fourier components of the waveform while retaining the dc magnitude information. A cutoff frequency of 500 Hz was chosen to minimize the transient response of the low-pass filter while still allowing for adequate filtering.

The analog output voltages from the low-pass filters are used to calculate the incident spot position relative to the PSD surface according to the following equations:
For the X position coordinate,

$$X_{pos} = \frac{V_{x_1} - V_{x_2}}{V_{x_1} + V_{x_2}} \tag{16}$$

and for the Y position coordinate,

$$Y_{pos} = \frac{V_{y_1} - V_{y_2}}{V_{y_1} + V_{y_2}} \tag{17}$$

where, V_{x1}, V_{x2}, V_{y1}, and V_{y2} are the analog output voltages representing the photocurrent magnitude information from the PSD.

A high-speed analog to digital converter board converts the analog output data from the IST to a 12-bit digital signal. The system computer performs the simple calculations to determine the X_{pos} and Y_{pos} coordinates of the IR spot based on equations (16) and (17). An algorithm based on statistical averaging and position probablity is performed over a number of samples to increase the effective resolution to 10 bits.

The objectives of the IST design were to maximize the speed and resolution with which the tracker can determine the X and Y weapon position coordinates for up to nine trainees. The PSD-based tracking system requires less than 3.0 milliseconds to generate the position coordinates of an imaged IR spot with a resolution of 10 bits; in contrast, a typical CCD-based tracking system requires over 30 milliseconds with similar resolution. Due to the simplicity of the PSD operating characteristics and

circuit design, a PSD-based tracking system can be built to cost several orders of magnitude less than a similar CCD-based tracking system.

CONCLUSIONS

Increased realism and effectiveness in simulator-based weapons team training can be realized through implementation of interactive aggressor targets and a high speed weapon tracking system. Continuously tracking weapon aiming points for all members of a fire team expands performance measurement capabilities. Training effectiveness and realism is also increased by instantly removing disabled aggressors from the training scenario and requiring trainees to take appropriate cover when an aggressor returns fire. This results in an increase in communication and awareness between members of the training team. In contrast, previous training systems did not require trainees to seek appropriate cover. Also, aggressor targets were not removed from the progressing training scenario when they were successfully engaged and disabled by trainees.

Prior to the implementation of the PSD-based tracker design, the replay scenario data collection process for two or more trainees, utilizing a CCD-based tracker, was only capable of generating the aiming point for each trainee at trigger-pull. This limitation, due to the relatively slow data rate of CCD-based trackers, severely diminishes the effectiveness in which the trainee performance can be evaluated. The PSD-based tracker offers a significant advantage over the CCD-based tracker in measuring the dynamic performance of multiple team members in a team engagement training system.

To overcome the disadvantages of the CCD-based tracking system, NTSC developed a low-cost, high-speed, infrared spot tracker which utilizes a two-dimensional lateral-effect photodiode, or Position Sensing Detector (PSD). The PSD is not a discrete charge transfer device such as the CCD, but rather a continuous analog output device. In contrast to other types of position sensing photo devices such as CCD detectors, the PSD offers higher resolution, faster speed, larger dynamic range, and simpler signal processing.

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RECOMMENDATIONS

The authors recommend development of an advanced prototype which would further increase realism in the training environment. An engineering model could be developed for potential user tests to determine both training and cost effectiveness. This engineering prototype could enhance both realism and performance measurements by:

(1) eliminating cords interfacing weapons to computers.
(2) allowing up to 9 trainees to rehearse tactical situations.
(3) using multiple screens to increase trainee mobility;
(4) tracking each trainees movements within the training area to both control shoot-back and enhance feedback.
(5) presenting results in a split screen display to show both trainee movement, aggressor actions, and others results.
(6) analyzing the performance results using an expert system.
(7) using an expert system to generate aggressor actions based on team performance.

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REFERENCES

G. Lucovsky (1960). Photo-effects in nonuniformly irradiated pn junctions. Jornal of Applied Physics, 31, 1088-1095.

W.P. Connors (1971). Lateral photodetector operating in the fully reverse-biased mode. IEEE Trans. Electron Devices, 18, 591-596.

H.J. Woltring (1975). Single-and Dual-Axis lateral photodetectors of rectangular shape, IEEE Trans. Electron Devices, 22, 581-586.

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